Galileo

Bringing Jupiter To Earth

Galileo Activity Guide

"America's future demands investment in our people, institutions, and ideas. Science is an essential part of that investment. . . ." So states the Clinton administration's policy statement, "Science in the National Interest." NASA has accepted the responsibility to contribute to this figurative "call to arms" and has challenged its Centers and its individual projects to develop programs which use the thrill of discovery to better capture the imagination of our elementary and secondary school students and teachers.

Called "educational outreach," these programs involve the development of various products which are designed to help make existing math and science curricula more exciting and relevant. Galileo has very actively contributed to this endeavor with the production of slide sets, posters, lithographs, on-line resources, and other multimedia materials. (The accompanying information sheet, "The Galileo Resource Guide," provides a list of resources and includes information on how to obtain them.) We're especially interested in finding ways for teachers to incorporate these materials and activities into their classrooms and in getting feedback from teachers as to how Galileo can best serve their needs.

This activity guide outlines some suggested classroom activities that incorporate Galileo educators' resources. Many of these activities are similar to the actual type of work performed (or the techniques used) by scientists and engineers working on the project. Similarly, the suggested discussion topics reflect the types of questions that scientists and engineers would raise in the course of their work.

One of the most important contributions to making the most of outreach products is teacher feedback. Suggestions and criticism are always welcome, either by mail (Galileo Educational Outreach, JPL, 4800 Oak Grove Drive, MS 264-419, Pasadena, CA 91109), email (askgalileo@galileo.jpl.nasa.gov), or fax (818) 354-6256.

Content, by subject:

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Note: for information on obtaining the resources used in these activities, please refer to "The Galileo Resource Guide," available on-line at http://www.jpl.nasa.gov/galileo/resources.html.

SOLAR SYSTEM/SPACE SCIENCE

1) Where in the Solar System is Carmine SanDimas? (All ages)

Resource used: Educator's slide set #1 (Images available at http://www.jpl.nasa.gov/galileo/slides/)

Activity description: Students must guess (or figure out from clues) where in the solar system each picture was taken.

Make it easier:

- List possible place names (but one name can be used more than once)
- Stick to visible light pictures

Make it harder:

- Use lots of Earth photos, especially those taken in non-visible wavelengths. What different features do you see when looking in two different wavelength ranges?
- Show images of the same place, but in different wavelengths (e.g. Venus)

Discussion afterwards: Did this look like you'd expect (place name) to look? Why or why not? (this is particularly effective when showing Earth pictures). What types of features can you see?

2) Which way is "up?" (All ages)

Resource used: Educator's slide set or lithographs

Activity description: There's really no up or down in outer space, but that's not always easy for students to see (or believe).

- Randomly orient the slides or lithographs, and show them to the students, asking them to say which ones they think are oriented "right side up" and which ones are "upside down" or "sideways." Some particularly good examples: Antarctica lithograph (should "South" be down, or should "ground" be down?) and Galileo deployment shot.
- Another approach is to take a lithograph hanging up in the classroom, and rotate it 90 degrees every few days (astronaut images are great for this).

3) Sculpting an Asteroid

Resource used: Educator's slide set (slides of asteroids Gaspra and Ida)

Activity description: Students try to reconstruct what an asteroid looks like in 3-d from two-dimensional images (very similar to the work that scientists perform, although they use image processing software)

Using modeling clay[1], try to "reconstruct" each asteroid in 3-d.

Easier:

- Have students make their own "asteroids" from clay. Make sure that each asteroid has a distinct shape, bumps and a cratering pattern. (you might also try smashing up a huge block of plaster of paris, which is more akin to how some asteroids are created).
- Take photos (polaroids would work well) from different angles of one of the objects. This is more dramatic if you strongly light the "asteroid" from one side.
- Give the students the photos of the "asteroid," and then have them pick out the object in the pictures from all of the other "asteroids."
- More challenging: give the pictures (in order) to teams of students, and have them reconstruct the "asteroid" from modeling clay.

4) Are all asteroids' surfaces the same age?

Resource used: Educator's slide set or lithographs

Background: Asteroids may well crash and bump into each other. They may fracture into smaller bodies. Or they may get lucky and continue, unmolested, along their orbits. Can we find any differences in Galileo's flyby images of Gaspra and Ida that would suggest they are different ages? (answer as of July 1995: preliminary evidence is that Ida's surface is older, but scientists are still checking data that will tell them what the surfaces of the two asteroids are made of, which may modify the answer).

Activity description:

1. Tape up a large piece (5' x 3' piece of butcher paper, for example) of paper with big grid marks. Or, draw a grid on a white board.

2. Project the slides of Gaspra and Ida (to project these at the same scale, put the slide projector about 3 times further away when projecting the Ida slide (you can also have your students work this out, given the true sizes of Gaspra and Ida). Putting the projector at roughly 18 feet from the screen, I could use 5" x5" squares to represent 5 x 5 kilometer areas. At the edges, as the asteroid curves away, each square will end up covering much more area (foreshortening), so you may want to ignore these areas.

3. Assign two or three students to count the craters in one or two squares. An easy way to count is to circle each crater after it's been counted. Use a different color marker for each asteroid.

4. Think a little about how we make these counts: do all the students agree on what is and on what isn't a crater (it's not always easy to tell!)? How would scientists make sure that something is or isn't a crater?

Easier level activities:

- Calculate the average number of craters per square (or per square kilometer, if your students have made up a scale for the image) for each asteroid. Which asteroid (if either) has more? Should an older asteroid have a higher or lower crater density? Why? How is this like

[1] To make your own play clay, mix 1 cup flour, 1 cup warm water, 2 teaspoons cream of tartar, 1 teaspoon oil, 1/4 cup salt, and (last of all) food coloring. Stir over medium heat until smooth (dough will be fairly stiff). Let cool, knead until smooth. Stored in airtight bag or container, this will last for some time.

counting scratches on two different cars (both driven by the same person)? Or, like scratches on glasses lenses? Dents on bicycles? Folds on dollar bills?

- How big is the biggest crater you can see on Gaspra? on Ida? (easier—are the biggest craters on both asteroids the same size?)
- How big is the smallest crater that you can see on Gaspra? on Ida? Is there a difference between the two? If you can see smaller craters on one asteroid, why would it be so?
- What is the crater density per square (or per square kilometer) on each asteroid (watch out for foreshortening!)?
- Are the crater edges "crisp" or "weathered?" Which type is older, assuming that there's no change in the material that they're made of?
- Are there craters that have other craters on top of them? How does this happen? Do you see these on both Gaspra and Ida?

More advanced:

- Given that Gaspra is 17 kilometers (10 miles) long by 10 kilometers (6 miles) wide, and Ida is 58 kilometers (35 miles) long and 23 kilometers (14 kilometers) wide, construct a map scale (e.g. 2.5 cm = 1 km).
- Which direction is the Sun coming from in each image? How can you tell? Is it easier to count craters when the Sun's light is shining directly onto the surface, or when the Sun's light is coming at an angle? Why?
- "Bin" the data: how many craters can you count on each asteroid that are at least as big as the bottom of a dixie cup? as a quarter? as a dime? Calculate the average density of large craters per square kilometer, or quarter-sized craters per square kilometer. Do these vary between the two asteroids?
- Do you see any "pairs" of craters that look like they're about the same age? Scientists think that these craters may possibly be due to a string of impacts akin to the Comet Shoemaker-Levy/9 comet impacts with Jupiter, where a rain of impacts leaves behind a chain of craters.

5) Where's the Earth?

Resource used: Arrival at Jupiter Poster

Activity description: Viewing the solar system from Jupiter looks quite different than seeing it from Earth. Here's how to orient your students:

- Outside, lay out a model solar system that will include (in this case) just the location of the Sun, and the orbits of Earth and Jupiter. One way to do this is to make one student the Sun, have her hold onto one end of a rope the radius of Earth's orbit, and have another student ("Earth") hold onto the other end and walk in a circle around the Sun while tracing his path with a piece of chalk (this works better on asphalt playgrounds than on grass). Then, trace out Jupiter's orbit. Jupiter's orbit has a diameter 5.2 times larger than the Earth's orbit; a 5-foot diameter Earth orbit and a 26 foot diameter Jupiter orbit would work fine.
- How big does "Earth's" orbit look from "Jupiter's" orbit?
- Locate the Sun on the poster. Does it look like the Sun, a planet, or a star at this distance? Based on your experience with the model solar system, can you estimate where the Earth would be located on the poster?

A little harder: (requires a little trig)

- Given the information above, what angle will the Earth's orbit subtend in the sky when viewed from Jupiter (arctan(1/5.2) = 11° on each side, so the total orbit subtends a 22° orbit)? Indicate this area on the poster.
- Another clue: The spacecraft's antenna (see back of poster for location) must be pointing to within about 4° of Earth (as seen from the spacecraft) in order to maintain the best "downlink." Based on this, can you better limit where the Earth is located?

For discussion: If the spacecraft got confused, how would it start finding Earth? (look for the Sun first!)

6) Other Activities

- "The Jovian System: A Scale Model" is a kinesthetic activity that gives students an idea of the size and scale of the Jovian system and also illustrates the Galileo spacecraft's arrival day trajectory. It is available as a handout or on-line.

PHYSICAL SCIENCE

7) Great Red Spot pinwheel

Materials used: Great Red Spot rotation "blink" movie (optional)
(available at http://www.jpl.nasa.gov/galileo/ganymede/092396.html)

Grade level: junior high

Background: The Great Red Spot is an intriguing, gigantic, cyclonic storm on Jupiter that has lasted for at least 300 years. It looks similar to Earth's hurricanes but is much larger -- two Earths would fit inside that storm! Also, while Earth's storms get their energy from the Sun and are much shorter lived, Jupiter's storms are mainly driven by the heat coming from within the planet.

This activity can be used in a math context (measuring speed), or a science context (atmospheric dynamics -- understanding that there's lots of interaction going on within the Great Red Spot system). Or, it can simply be used to illustrate that we can understand what we see and represent in an understandable way (in this case, by experiencing what it might be like to "be" the Great Red Spot").

Activity description: If possible, show the Great Red Spot rotation movie and/or complete the Great Red Spot rotation speed exercise. Where is the storm rotating the fastest? The slowest? Does it all rotate in the same direction?

It takes 6 days for the Great Red Spot to make one rotation. Assuming that each part of the storm takes the same amount of time to rotate (which isn't quite true), the outer part of the storm must travel faster because it must travel farther in those 6 days.

Have some students (6-8 or so) stand in a line and have them rotate like a pinwheel (representing a "slice" or "spoke" of the storm). To keep them in a straight line, have them hold hands or onto a rope or a long stick -- or have them slowly take one step at a time and make sure they are in a line after each step. Either way, students will quickly realize that those on the outside must take bigger steps (hence traveling a greater distance for each unit of time, which in the second case is one "step" command).

Who is moving the fastest? The slowest? Add another line of students like a spoke and have them continue rotating. What happens? What if there are 3 or 4 lines of students rotating? What if you represent the whole storm (like a crowded skating rink)?

Students will start bumping into each other, especially on the outside where they must move faster. This is representative of what happens in cyclonic storms like the Great Red Spot. For further discussion, make the storm move faster or slower and notice the frequency with which students bump into each other.

This activity can lead to a number of spin-off discussions about atmospheric dynamics, rotation speed, and the difficulty of modeling complex, dynamic activity. (Think about how complex it would be to mathematically represent the Great Red Spot's with an equation, or even with discreet points.)

8) Floating in Jupiter's atmosphere

Materials used: helium balloon on a string, small piece of cardboard

Grade Level: high school

Background information: Scientists have wondered if it might be possible to do a long-term survey of Jupiter's atmosphere by using some kind of balloon spacecraft -- that is, instruments hanging below a balloon. However, Jupiter's atmosphere is composed mostly of hydrogen, which is the lightest element. How would you figure out whether or not something could "float" in its atmosphere? We examine this question, which is an application of Archimedes' principle, with a comparison to a balloon "spacecraft" floating in Earth's atmosphere.

Activity description: Let the helium balloon rise. Why does it do that? Helium is a gas that's much lighter than air. Or, more accurately, the helium gas inside the balloon is much less dense than the air outside, causing the buoyant force upward to be greater than the gravitational force downward.

Attach the cardboard to the balloon's string so that the system does not rise. (The "system" consists of the gas, balloon, strong, and cardboard -- you can call it a "spacecraft," since that's what it represents for this discussion.) Why doesn't the spacecraft rise anymore? (Answer: the average density of the spacecraft, which is the combined masses of the balloon, gas, string, and cardboard divided by their total volume, is greater than that of the air.)

Trim a little bit of the cardboard off at a time until the spacecraft lingers in midair. Explain that this is the point at which the density of the spacecraft is roughly equivalent to the density of the air. (You can also talk about forces and buoyancy, depending on what the students know and on what they're studying.)

In order to design a "real" spacecraft to float in Jupiter's atmosphere, you'd have to make some similar considerations -- compare the overall density of the spacecraft to the density of the atmosphere. But, Jupiter's atmosphere is composed mostly of hydrogen, which is the lightest element. How would you get something to "float" in such an atmosphere?

Two possibilities:

(1) Use a heated, lightweight gas. (The heat would expand the gas, causing the same "amount," or mass, to have less density, making it more buoyant. To validate this idea, think about a hot air balloon that uses regular air as its gas.) Or,

(2) Use pure hydrogen. (Jupiter's atmosphere also has other, heavier elements such as helium, so pure hydrogen gas would be lighter.)

Either way, the overall (average) density of the spacecraft (including the gas) would have to be equal to the density of the atmosphere at the depth you want to explore. In other words, the mass of the spacecraft (gas+balloon+instruments) can't be more than that of the gas (in Jupiter's atmosphere) that it pushes aside, or else it will sink.

Of course, there are several other things to consider. For example, in addition to being able to survive the trip to Jupiter and into its atmosphere, the spacecraft would have to be designed to operate in a range of conditions (temperatures, pressures, densities, etc.) that vary with depth. And, of course, it would need a way to *get* to Jupiter, a way to send information back to Earth, and so forth.

9) Other Activities

- The "Storms on Jupiter" Educational Monograph contains an activity that leads students through the calculation of the speeds of the winds in the Great Red Spot.

MATHEMATICS

10) Jupiter's Relative Size

Materials used: About 1400 small jellybeans (or pinto beans/other kind of beans)
Fishbowl to hold at least 1000 beans
Small Dixie cup

Grade level: lower elementary (upper elementary for advanced discussion)

Background information: Jupiter is about 1,400 times the size of Earth (by volume), but that's difficult to believe, since it appears so small in the sky. It's also difficult to visualize just how big something 1,400 times bigger than Earth would be.

Equally hard to believe is that 1,000 Earths would fit inside the planet Jupiter. Since the Earths can't fit exactly side-by-side, there is space remaining in-between -- space the volume of 400 Earths!

We can illustrate these points with the following exercise, approximating (roughly!) the Earth's size and shape by a bean.

Activity description: After talking about the planets and explaining that they are of different sizes, impress students by telling them that about 1,000 Earths would fit inside Jupiter. Show the students 1 jelly bean and ask them: if this were the size of Earth, how big would Jupiter be? Show them the fishbowl and mention that it would be about the size of Jupiter, if Earth were the size of a jelly bean.

How could you prove this? Ask them for ideas. They might suggest that you put the jelly beans in and count. But it might take awhile to count 1000 jelly beans. If you count how many beans will fit into a small Dixie cup, can you figure it out faster? Try estimating the size of Jupiter by counting how many beans fit into a small Dixie cup, then measure them in scoops. (E.g., If 50 beans fit into each Dixie cup, then it will take 20 cups of jelly beans.)

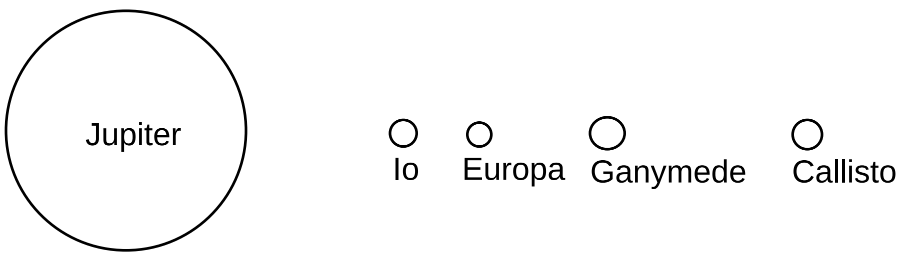
To illustrate that Jupiter is 1400 times bigger than Earth (by volume), then you'd have to squish the beans and add about 400 more. Alternatively, you can fill those Dixie cups with water and estimate how many more "Earths" would have fit in-between the cracks.

You can do different variations on this exercise based on what information you give the students and what you ask them to figure out.

For reference, by the way, Jupiter's volume is roughly 1.53×10^{15} km^3; Earth's is about 1.09×10^{12} km^3. (Their equatorial radii are 71,492 km and 6,378 km, respectively.)

More advanced discussion: This discussion warns students that the scales of diagrams they see may *not* always represent a true scale. It also illustrates some reasons why it might be useful to present this kind of "false advertising."

When making solar system models, sometimes the planets and their moons are not quite to scale. For example, Jupiter should be about 11 times bigger by diameter (1400 times bigger by volume) than Earth, but in diagrams, the two planets often appear to be closer in size. More dramatically, Jupiter is about 46 times bigger by diameter (396,000 times bigger by volume) than its moon Europa. Take a look at the diagram below, in which the relative sizes of the moons are exaggerated. Why would we want to do this, since it's inaccurate?



<u>Some possible answers:</u> In the most convenient model for the information we want to show, it might be impractical to make Jupiter 1400 times bigger than the size of Earth or 396,000 times bigger than Europa. Even in a 2-dimensional diagram, if we choose Europa to be the size of a dime, then Jupiter would take up 12 pages. (The area of a 2-dimensional outline of Jupiter would be 2,000 times bigger than one of Europa.) But even if we shrink Jupiter down to fit on a page, we can still show some basic relationships, such as (in a solar system model) which moons go with which planets and what order they're in. Or, perhaps the purpose of the diagram is to show the differences in surface features -- at the size of a dime, you couldn't show many surface features of Europa!

The Galileo CD-ROM designers had to think about this when they were designing a screen representing the Jupiter system. They wanted people to be able to click on Jupiter or one of its moons, but if they drew it to scale with Jupiter about 10 cm in diameter, at about 2 mm in diameter, you would hardly be able to see the moons on the screen. Certainly, users wouldn't be able to distinguish one from another. So, the CD-ROM designers decided to make the moons much bigger in comparison to Jupiter in that picture.

11) Spacecraft speed and acceleration

Resource used: Galileo WWW Page (http://www.jpl.nasa.gov/galileo/)

Activity description -- Junior High: put the spacecraft's speed into perspective.

Look at Galileo's WWW page, and find out how fast the spacecraft is traveling at the current time. How fast is this really? (either supply the data below, or have the students guesstimate, or have them add other examples)

- A human walks at about 7 kilometers (4 miles) per hour
- A human runs at about 22 kilometers (13 miles) per hour (marathon pace)
- A car's top (legal) speed in the US is 108 kilometers (65 miles) per hour
- A jet airplane can make 830 kilometers (500 miles) per hour
- Just prior to arriving at Jupiter, Galileo was traveling at 3,400 kilometers (2,040 miles) per hour (relative to the Sun)
- A satellite in low earth orbit travels at 28,000 kilometers (16,800 miles) per hour
- The Earth, moving around the Sun, has an average speed of 107,600 kilometers (64,560 miles) per hour
- Right after flying by Earth for the second time, Galileo was traveling at 152,640 kilometers (91,590 miles) per hour (relative to the Sun).

How long would it take to walk/drive/jet/Galileo from New York to California (5,000 kilometers (3,000 miles): 30 days, 46 days, 6 hours, and 2 minutes, respectively)? Or, if there was a direct road to Jupiter (which is, at a minimum, 630,000,000 kilometers (378,000,000 miles) from the Earth), how long would it take to make the trip walking/driving/jetting? (10,273 years, 666 years, and 87 years, respectively)?

Graphing all of this might make it easier to see in a glance how these speeds vary.

Easiest: have the students make up a linear graph that will show all of the speeds, using a long piece of butcher paper (which may need to wrap around several walls!). Cut out pictures to illustrate the data points (e.g. a woman walking or a drawing of a satellite).

More advanced (introducing logarithms): Have the students try three different methods (see attached illustration). Which graph makes it easiest to "read off" the actual speed of each object? Which graph makes it easiest to compare the speeds of each object?

Linear graph: Each tick mark indicates an equal number of kilometers per hour. Drawn on a sheet of notebook paper, differences between running, walking, and a car are easy to see, but nothing else fits on the graph.

Linear graph with expanded scale: Each tick mark indicates an equal number of kilometers per hour. Drawn on a sheet of notebook paper, humans, cars and planes all appear to move at the same speed.

Log graph: Each tick mark indicates a factor of 10 <u>increase</u> in the number of kilometers per hour. This makes it easy to tell that, for example, Galileo was moving roughly 100 times faster fight after the second Earth flyby than it will be moving right before arriving at Jupiter.

Activity description --Senior High: acceleration and deceleration

Monitor Galileo's speed (from the Galileo WWW page) over several days. What is happening to its speed? Is it changing or staying stable?

Monitor the spacecraft's speed with respect to Jupiter for an entire orbit (roughly 40–50 days). Plot the speed versus distance from Jupiter. When is the spacecraft traveling fastest (near Jupiter)? Slowest (furthest from Jupiter)? Does the spacecraft ever "stop" moving (i.e. does its velocity ever reach 0)? Is there ever a major change in speed (right at the time of the satellite flyby--this is the so-called gravity assist)?

The spacecraft speeds up and slows down as it orbits around Jupiter; as it moves closer to Jupiter, the gravitational force that Galileo feels increases. When Galileo is traveling further from Jupiter, the gravitational force decreases. The greater the gravitational force, the stronger the acceleration that Galileo feels.

To see this in action, plot the Galileo's acceleration as a function of distance from Jupiter. Just as velocity is the change in distance that occurs in a given time, acceleration is the change in velocity that occurs in a given time. Calculate the (average) acceleration that Galileo feels for each day using the formula

$$\text{Today's acceleration} = \frac{\text{Today's speed} - \text{Yesterday's speed}}{\text{24 hours}}$$

(if you want to use the velocity changes on an hourly basis, adjust the time you're dividing by appropriately). What units do you want to express the acceleration in? kilometers per second per second? kilometers per second per day?

For comparison, have the students call up an auto dealership and find out how fast the dealer's cars can accelerate or decelerate (if the dealer gives the numbers as "goes 0 to 60 in 10 seconds," this can be converted to acceleration by the dividing speed change by time interval). You can also compare this to the acceleration due to the Earth's gravity when standing on the Earth's surface (9.8 meters per second per second).

12) Data Transfer and Codes: BASE 2

Resource used: Curriculum Module #1

Activity description: Here is one suggestion for expanding the curriculum module into a math unit that shows that all this base 2 addition isn't just busywork:

It's 20 years in the future, and, instead of having to carry textbooks back and forth to class, students read them on their home computers. This means that at the start of each class, or at home you don't keep the entire book stored on your computer (it takes up too much room, and crowds off the games), but instead, you "download" just the chapters that you're working on.

The computer can only communicate in a limited fashion: it can only recognize something as being a "on" or "off" (much like Morse code, which recognized short "dots" and long "dashes"). So, we have to come up with a "code" that will tell the computer "this is an a" or whatever. However, we want to be able to send the data back and forth as quickly as possible, so we also want to minimize the number of "on" and "offs" that have to be sent.

Have the students come up with a code that will cover each letter. For example,

a = (on)
b = (on)(on)
c = (on)(on)(on)
etc.

with "off" signifying the end of a letter.

Spell out the words "zebra" and "milk" in your code. How many bits of information does this take?
zebra = 26 + 5 + 2 + 18 + 1 + 5 offs = 57 bits
milk = 13 + 9 + 12 + 11 + 4 offs = 49 bits

How many bits of information, on average, will it take to identify each letter? (14)

Is there any way to minimize the number of bits that will get used on average? (some letters occur more frequently (e.g. e, s, t); assign those letters to a smaller number of "ons")

Also, we must account for capital letters, punctuation, and numerals. How many characters total do we need?

a-z = 26
A-Z = 26
numbers, punctuation, etc. (count keys on keyboard) = 42
94 characters needed, total.

Having to write out 94 (on)s is going to get tedious! Let's try another possibility. Make each letter exactly 7 bits of information long. Then, you could have (for example)

a = (off) (off) (off) (off) (off) (off) (off)
b = (off) (off) (off) (off) (off) (off) (ON)
c = (off) (off) (off) (off) (off) (ON) (off)
d = (off) (off) (off) (off) (off) (ON) (ON)

and so on; moving from the right, we keep turning on little switches. This scheme has some nice advantages: every letter or bit of punctuation only takes up seven bits of data.

Why seven bits?

If we had a code that said that each letter can only be one bit long, the computer would only receive two possible letters: (on) would be one letter, and (off) would be the other letter. If your entire vocabulary consists of the word "og," this is no problem, but it would definitely hinder conversation in English.

If each letter could be 2 bits long, then we would have these possibilities:

(on)(on)
(on)(off)
(off)(on)
(off)(off) = 2 possibilities x 2 possibilities = 4 possible letters

If letters could be 3 bits long, what would the possibilities be?

(on)(on)(on)
(on)(on)(off)
(on)(off)(on)
(on)(off)(off)
(off)(on)(on)
(off)(on)(off)
(off)(off)(on)
(off)(off)(off) = 2 possibilities x 2 possibilities x 2 possibilities = 8 possible letters

If we allow each letter to be 7 bits long, 2 x 2 x 2 x 2 x 2 x 2 = 128 possibilities, more than we really need (but 2 x 2 x 2 x 2 x 2 x 2 = 64, which is too few). Actually, computers assume 10 bits per letter: this allows for additional characters that aren't used in all languages (e.g. the British pound symbol) and for error checking (a way to ensure that the transmission is received without garbling).

Instead of writing (on) and (off), let's write 1 and 0. In this type of shorthand, the thirteenth number, for example, is written as 1101, where each "place" further from the right side increases by a factor of 2, compared with the numbers we're used to writing (where each place increases by a factor of 10). This is why we call normal numbers "base 10" and the other system "base 2;" we also see here that systems other than base 10 can have real-world uses (base 16 is also used for computer purposes, as is base 8).

What is meant by "bit rate?"

Have students come up with a list of different ways to send a message to a friend living 50 miles away (e.g. smoke signals, pony express, letter, telegraph, phone call, fax). Which ways are fastest? Which are slowest? How can we measure how fast each of these sends the data?

Spacecraft engineers (and computer engineers, too), talk about "bit rate," which measures how many bits of information can get sent by the computer each second. A home modem can easily send over 14,000 bits per second (bps). Let's see what bit rate really means:

a) Pick out a book, and count the words on one page. Have one student read the page out loud at "normal" speed while another student acts as timer. Try doing this as fast as possible, too, while making sure that the other person can actually understand WHAT you're saying. How fast can YOU read and still be understandable? (one JPL engineer, trying this, got out 4.4 words per second.).

Change this to a bit rate. Assume that there are 5 letters per word, and 10 bits per letter, so there are 50 bits per word. If you can read 4.4 words per second, that's 220 bits per second.

How long would it take you to read the entire book?

Now, let's make the problem harder. Go outside on a noisy street (or in front of a loud fan, or in the middle of a lunchroom), and, once again, read the page out loud. Notice how, if you read very quickly, the words get lost in the noise--you have to be careful and make sure that each word is clearly pronounced, which makes you slow down. What is your bit rate now? How low does your bit rate drop if you move 10 feet away from the person who is listening to you?

Just as your "bit rate" drops when you get further away, or when other noise interferes with your "signal," so too Galileo's bit rate drops when its signal weakens with distance, or when it has to overcome interference (such as when its signal has to pass near the Sun, which can generate a great deal of radio noise). Galileo will be communicating back to earth at a top rate of 160 bits per second. How long would it take Galileo to read the book?